CREATING THE LIVING NETWORK™

Air-Interfaces for Ultra-Low Power Communications – Challenges, Solutions and Potential Benefits

Tanbir Haque

6G Summit, March 2019, Levi, Finland

INTERDIGITAL

Evolution of Cellular Communications – From 2G to 5G & Beyond

5G and Beyond - A key challenge is to support trillions of connected things!!

1990+

10^6 increase compared to GSM!

	GSM-EDGE	WCDMA	HSPA	HSPA+	LTE	LTE-A	NR
Downlink Peak Data Rate	**240 kbps**	**384 Kbps**	**14 Mbps**	**42 Mbps**	**150 Mbps**	**1 Gbps**	**20 Gbps**
Spectral Efficiency	0.17-0.33 bps/Hz	0.51 bps/Hz	2.9 bps/Hz	12.5 bps/Hz	16.3 bps/Hz	30 bps/Hz	40 bps/Hz
Carrier Bandwidth	200 kHz	5 MHz	5 MHz	5 MHz	Up to 20 MHz	Up to 100 MHz	400 MHz
Round Trip Latency	300 ms	250 ms	~70 ms	~40 ms	~30 ms	~20 ms	~1 ms

← **2G** → **Millions** of voice users

← **3G** → Broadband Era … for the few

← **4G** → **Billions** of mobile broadband users

← **5G+** → **Trillions** of devices

InterDigital's 6G Vision – The Air-Interface

"Zero-energy" air-interface designs

THz Radio

Large swaths of spectrum and high number of antenna elements leading to Tbps rates

Ultra-Low Power Communications

- ✓ **Significantly improve device battery life**
- ✓ **Enable scaling to Trillions of devices**

AI/ML Assisted Wireless

Intelligent, context-aware adaptive radio communications

Massive VLEO Satellite

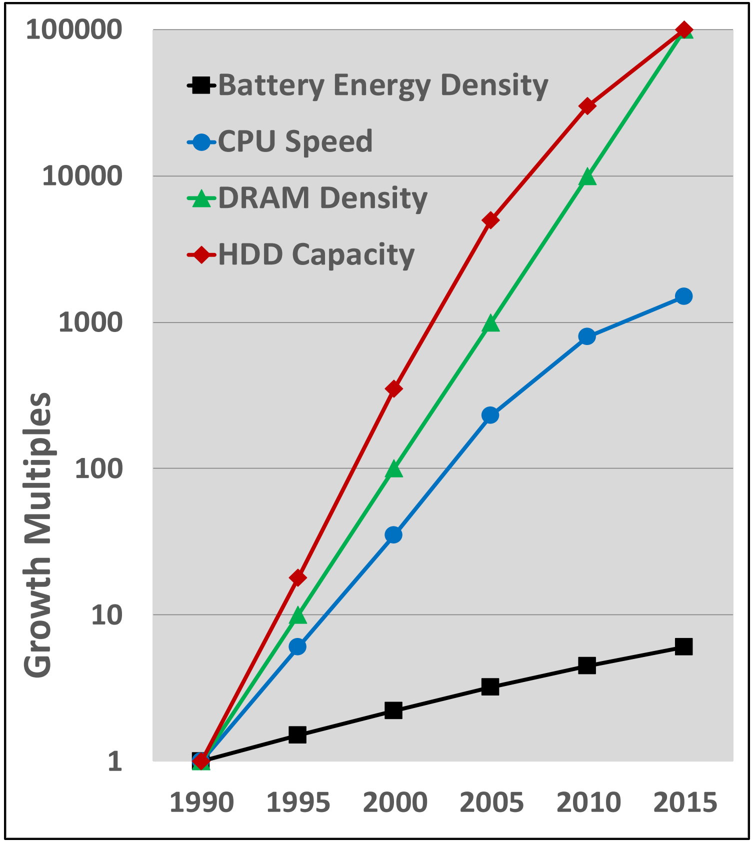
Very low-earth-orbit satellites providing low-cost ubiquitous connectivity to our planet

Quantum Communications

Leverage delivery of quantum information

Challenges in Scaling to 1T Devices – Battery Capacity

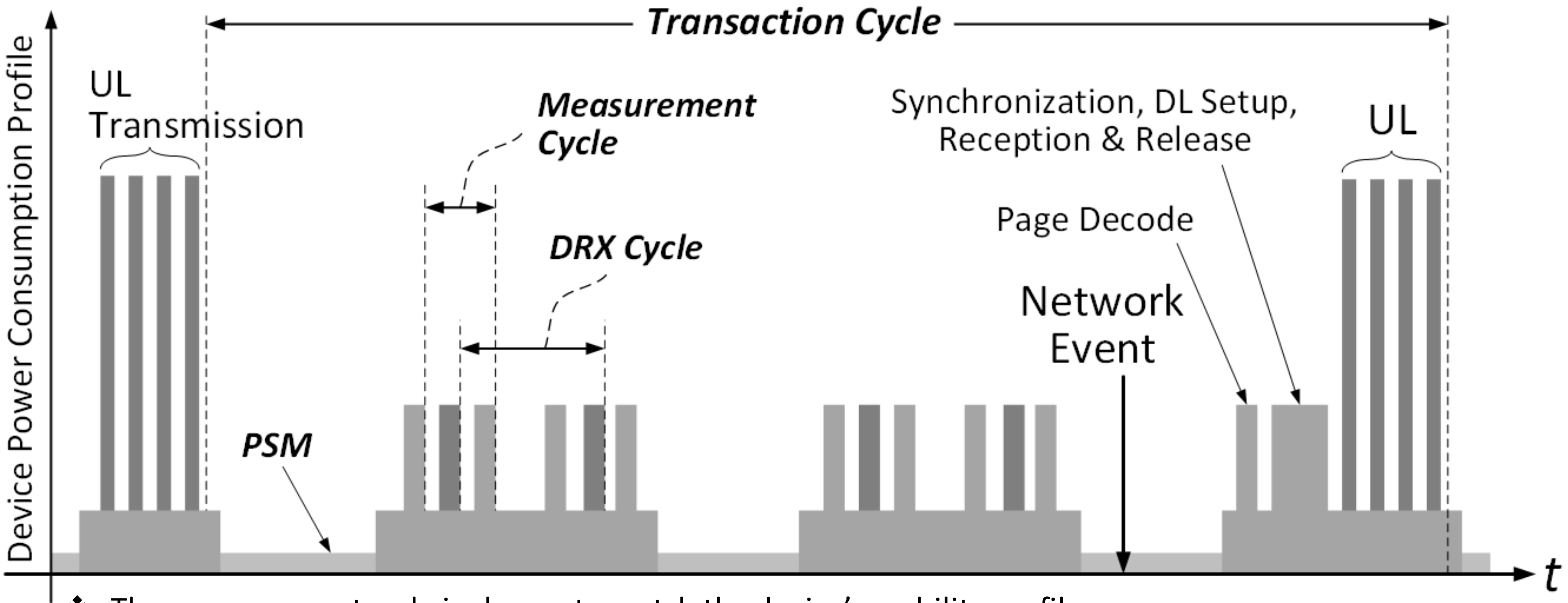
- Less than a 10x improvement in battery energy density from 1990 to 2015 compared to 100000x increase in storage density and peak wireless data rate
- Assuming 1T devices with 10 year battery life results in 274 million battery changes per day
- For some future deployments battery swapping will be difficult if not impossible
- Need to implement for-ever battery and enable battery-free device operation



Challenges in Scaling to 1T Devices – Latency vs Battery Life

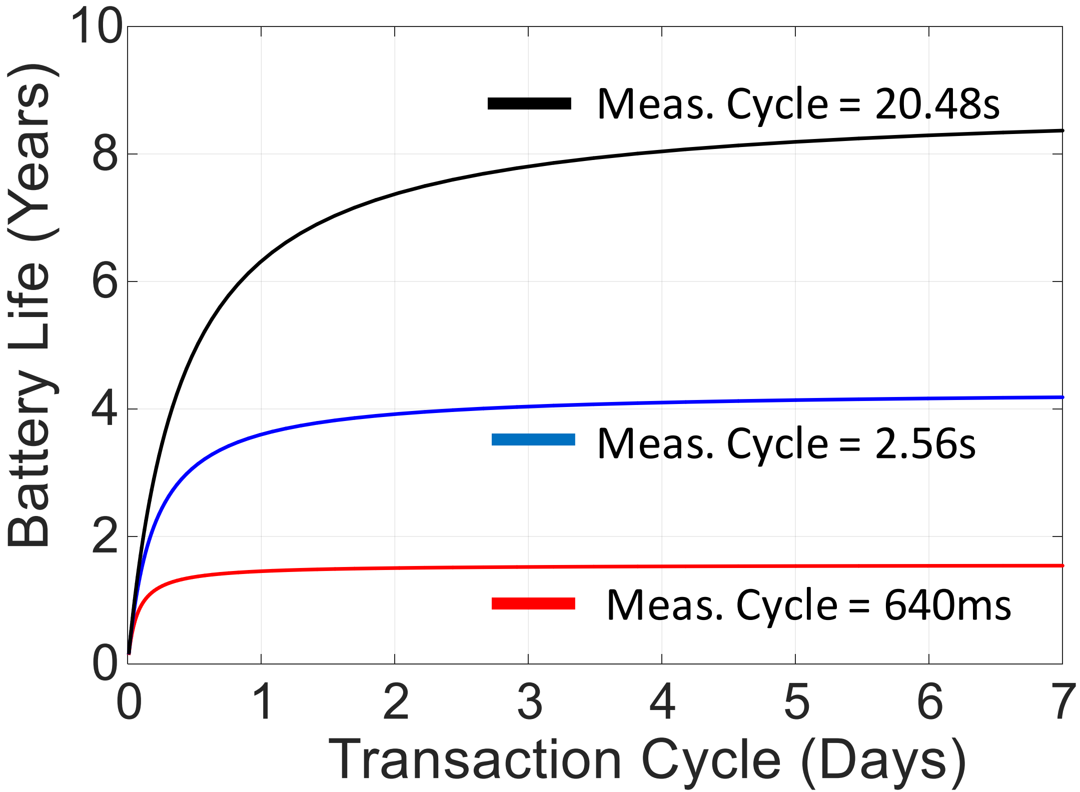
- DRX & PSM based approaches in 3GPP MTC & NB-IoT suffer from an inherent tradeoff between device reachability & battery life
- Longer DRX cycles result in extended battery life at the cost of latency
- Devices are not reachable during periods of deep sleep in PSM
- Furthermore, mobile devices must make periodic measurements for TAU procedures thereby limiting the maximum achievable battery life
- There is a need to introduce *on-demand features* to the 3GPP system framework in order to break this latency vs battery life tradeoff

3GPP DRX & PSM based Device Power Saving Mechanisms



- The measurement cycle is chosen to match the device's mobility profile
- The DRX and PSM cycles are chosen according to the latency and battery life requirements of the device

Device Battery Life with 3GPP DRX & PSM



- Two AA batteries
- Power class 4 transmitter
- UL packet size = 2 bytes
- DRX cycle = 20.48s
- PSM duty cycle = 75%

- 6 year battery life for a transaction cycle of 1 day
- 8 year battery life for a transaction cycle of 5 days

Scaling to 1T Devices – What is Needed & How to Get There?

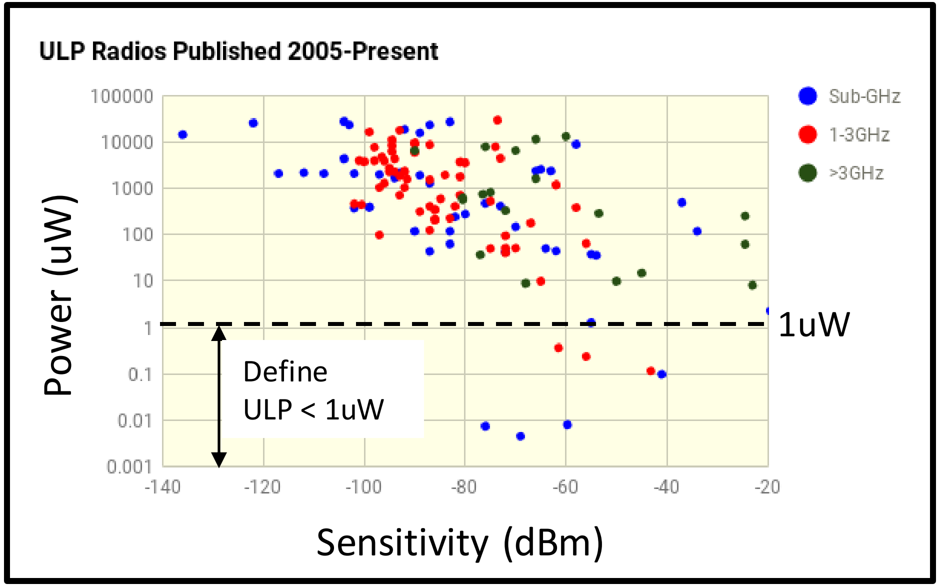
✓ Ultra-low power RF receivers capable of supporting macro-like link budgets

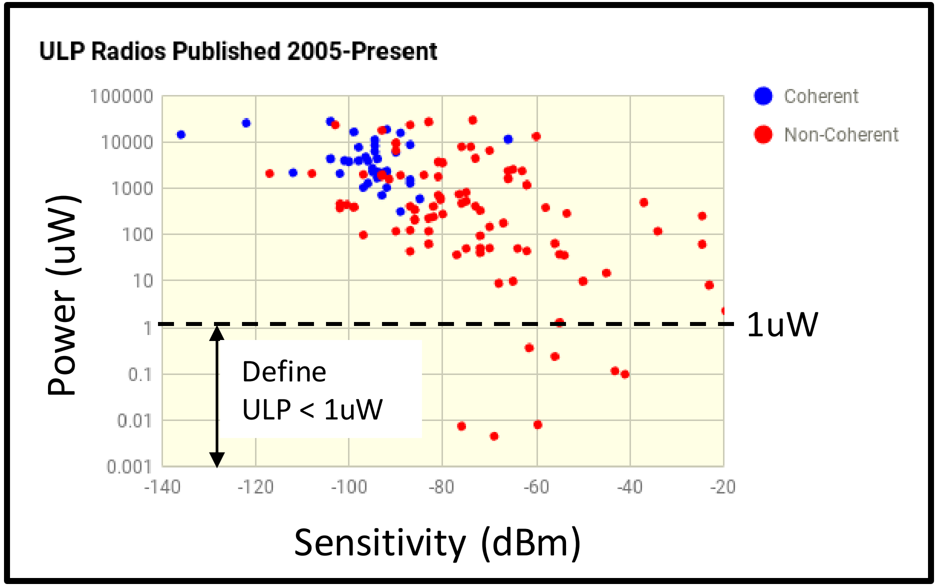
✓ A zero-energy air-interface that does not draw power from the device's battery

✓ A scalable system framework that can support a diverse set of deployment scenarios

A Brief Survey of Ultra-Low Power Receivers

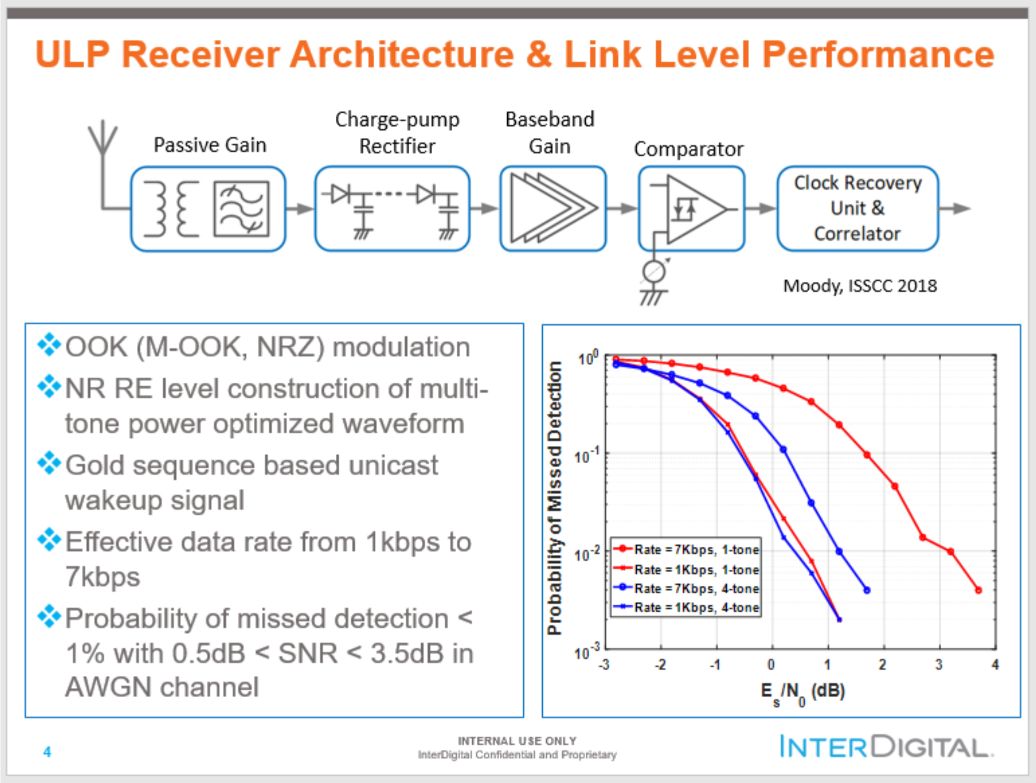
- Sub-1GHz frequency of operation
- Non-coherent reception
- Simple modulation schemes e.g. M-OOK





www.eecs.umich.edu/wics/low_power_radio_survey.html

Exploring the Feasibility of a ULP RX Enabled Downlink



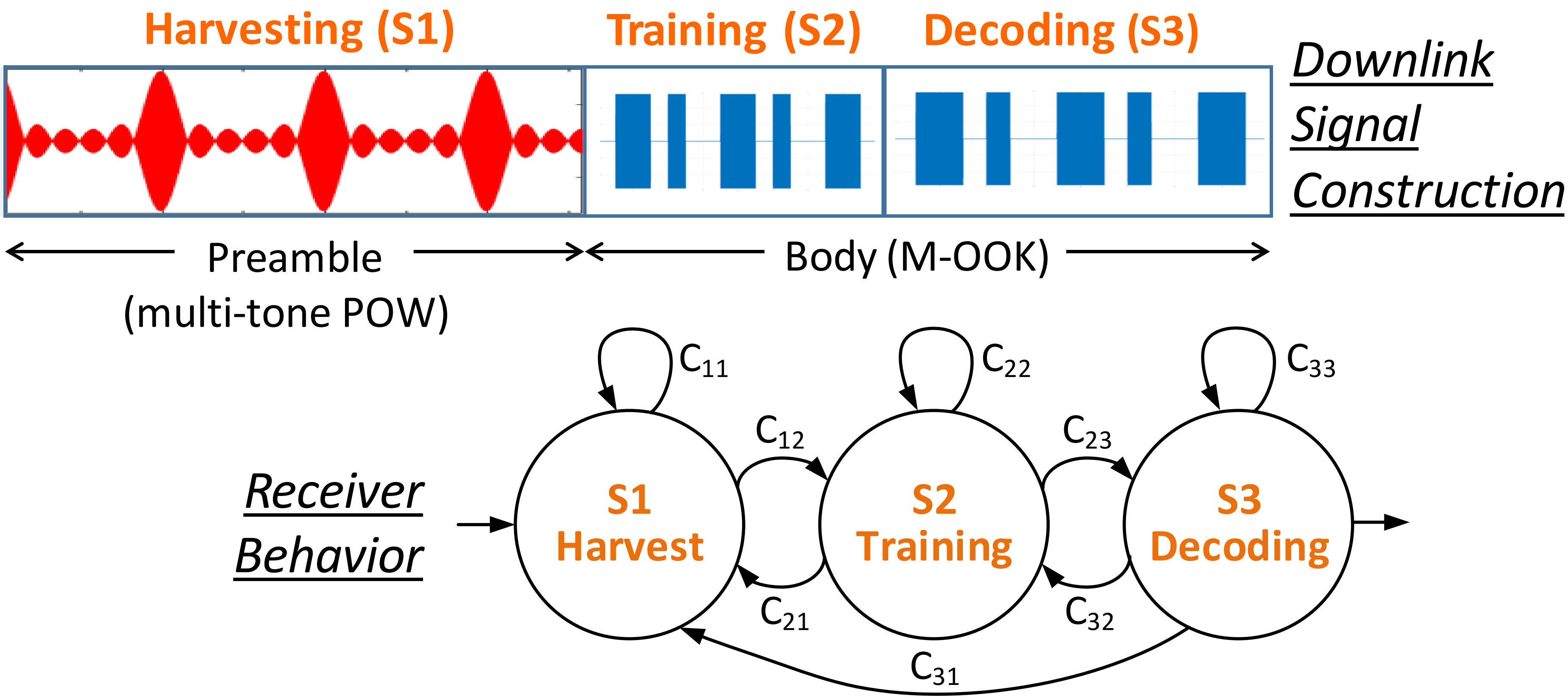
- ❖ The ULP receiver behavioral model was integrated into IDCC's 3GPP-NR link level simulator
- ❖ The receiver performance was evaluated in an AWGN & fading channel in the presence of narrowband blockers

Our research shows that 140dB FSPL at 900MHz can be supported with a 1kbps ULP receiver consuming < 20nW

Scaling to 1T Devices – What is Needed & How to Get There?

- ✓ Ultra-low power RF receivers capable of supporting macro-like link budgets
- ✓ A zero-energy air-interface that does not draw power from the device's battery
- ✓ A scalable system framework that can support a diverse set of deployment scenarios

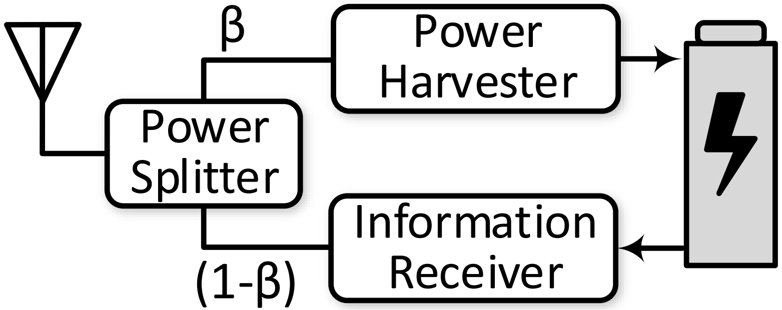
ZE Air-Interface Signals, Waveforms & Receiver Operation



Network Resources Needed for ZE Air-Interface Operation

$$E_H - E_{TRN} - E_{DCD} >= 0$$

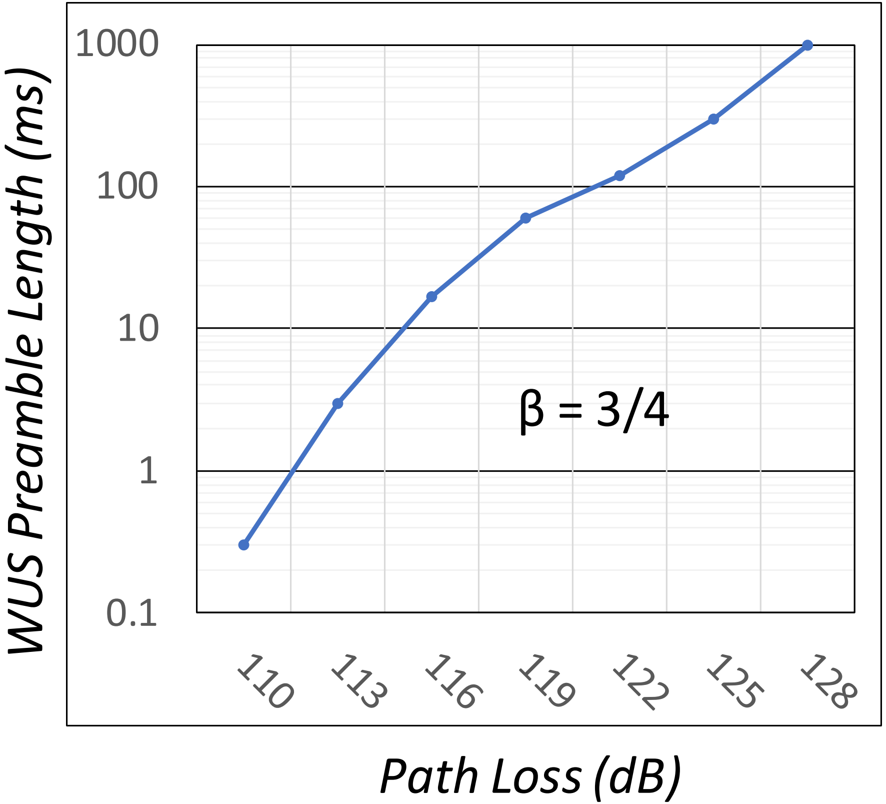
$$E_H = \eta\beta P_{RX} T_{PR}$$



$$R = \xi B \log_2\{1+(1-\beta)P_{RX}/N_0\}$$

$$E_{TRN} = (m/R)P_{rcv}$$

$$E_{DCD} = (N/R)P_{rcv}$$



Scaling to 1T Devices – What is Needed & How to Get There?

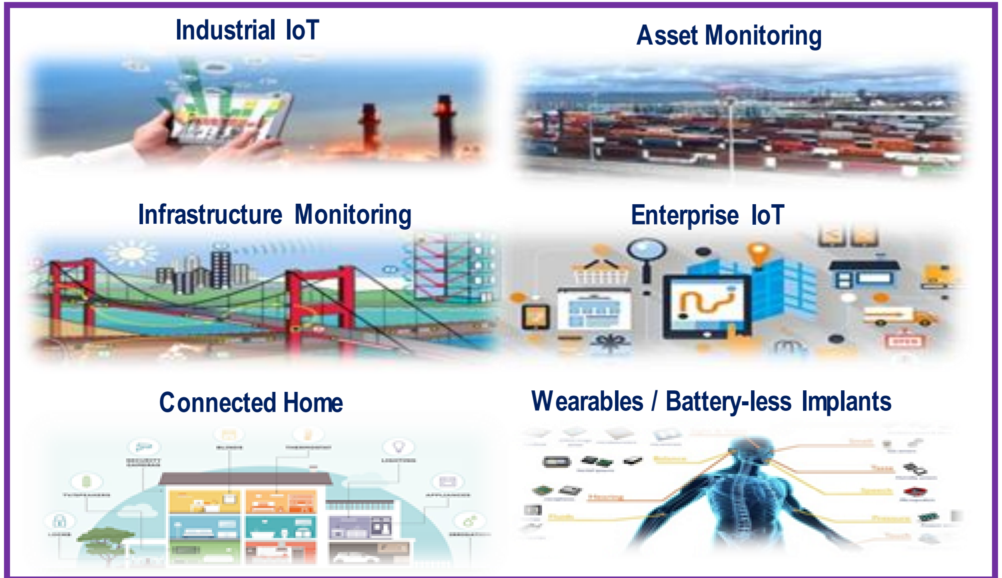
- ✓ Ultra-low power RF receivers capable of supporting macro-like link budgets
- ✓ A zero-energy air-interface that does not draw power from the device's battery
- ✓ A scalable system framework that can support a diverse set of deployment scenarios

Applications & Practical Considerations

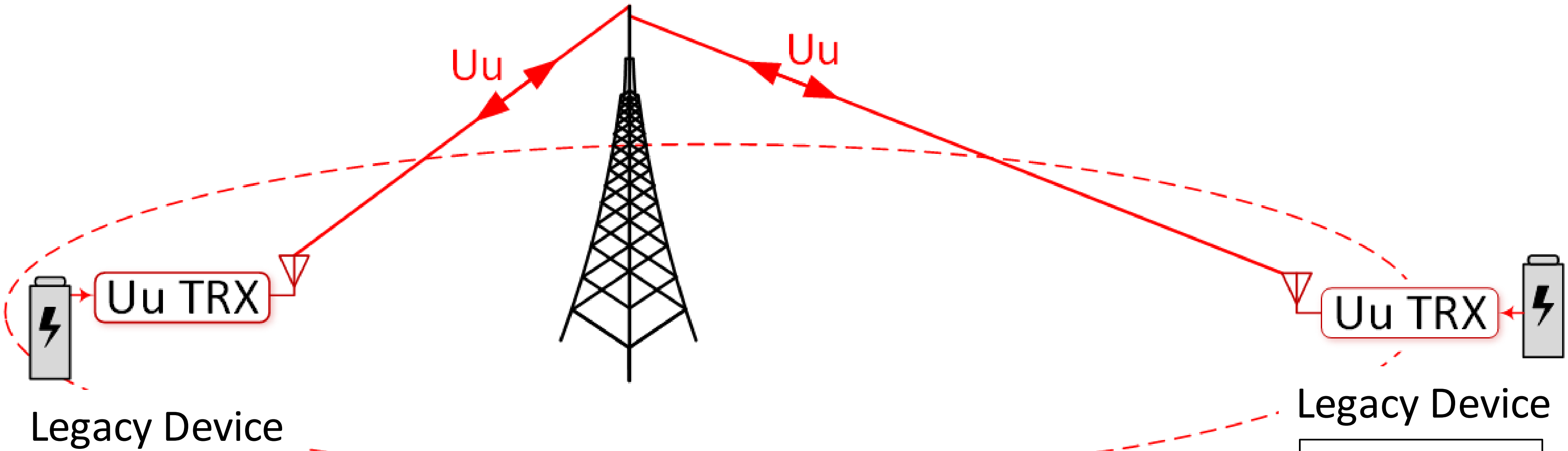
- Near term - enable up to 20 years increase in battery life with sub-1s network access latency for IoT devices

- Intermediate term – enable a host of new use-cases for e.g. connected homes with “for-ever” operation eliminating battery swapping during the life cycle of the device

- Long term – enable new classes of “battery-free” devices that are game changer for wearables and implants



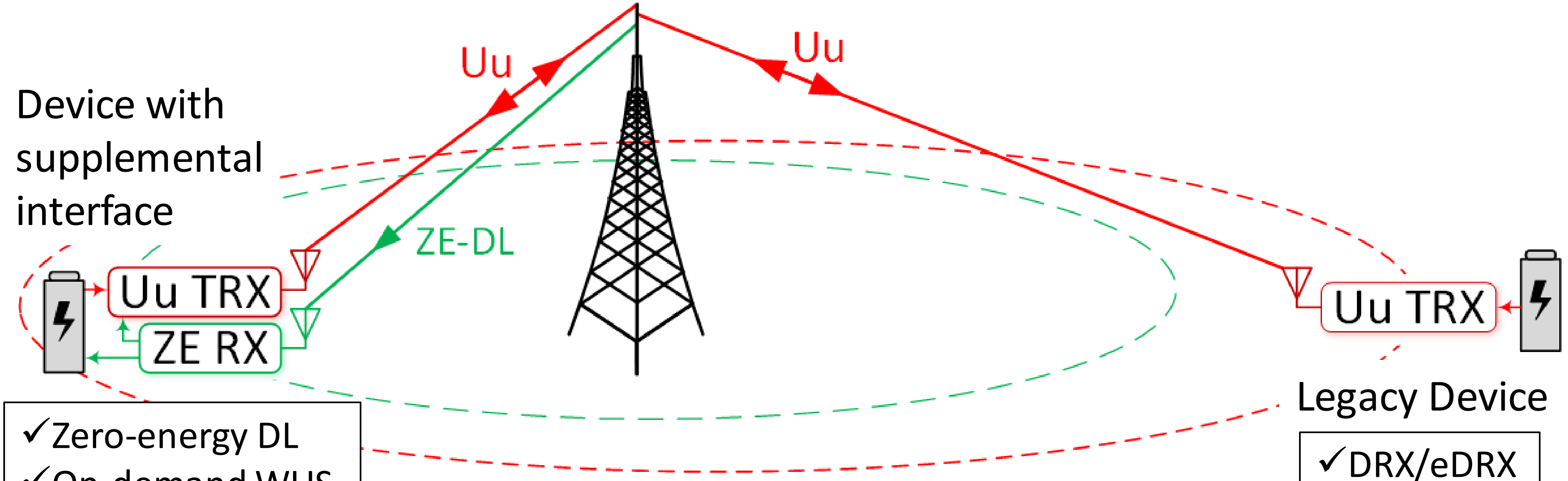
A Scalable System Framework to Support Diverse Deployments



- ✓DRX/eDRX
- ✓PSM

- ✓DRX/eDRX
- ✓PSM

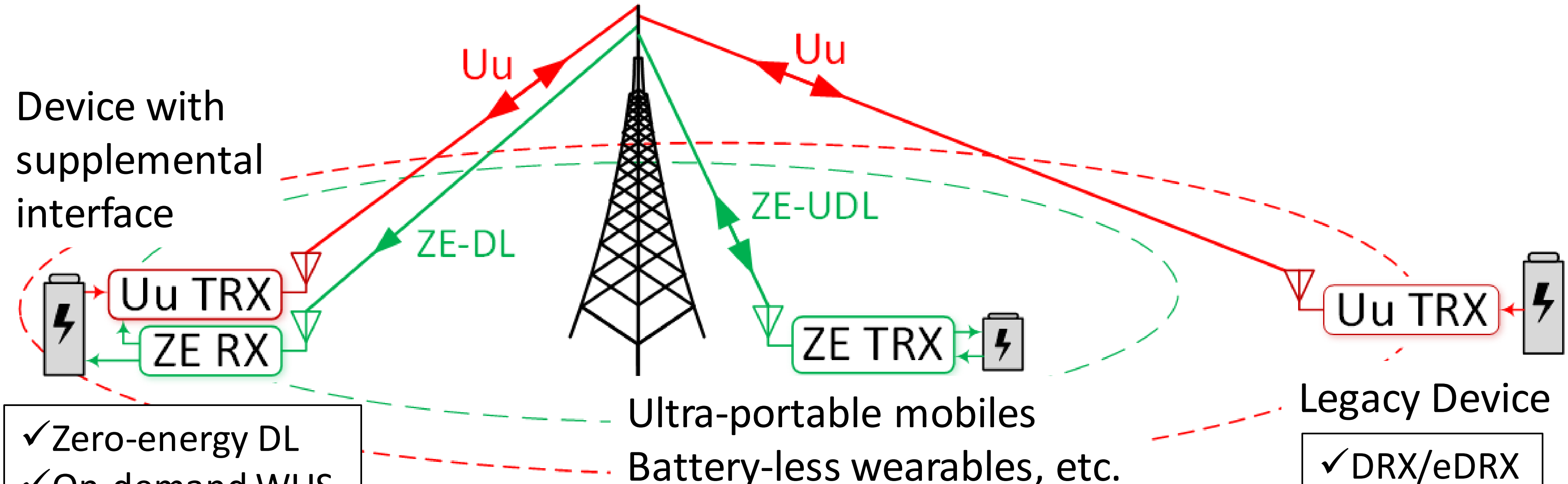
A Scalable System Framework to Support Diverse Deployments



- ✓Zero-energy DL
- ✓On-demand WUS

- ✓DRX/eDRX
- ✓PSM

A Scalable System Framework to Support Diverse Deployments



- ✓Zero-energy DL
- ✓On-demand WUS

- ✓Zero-energy DL & UL
- ✓On-demand WUS
- ✓Wireless power transfer

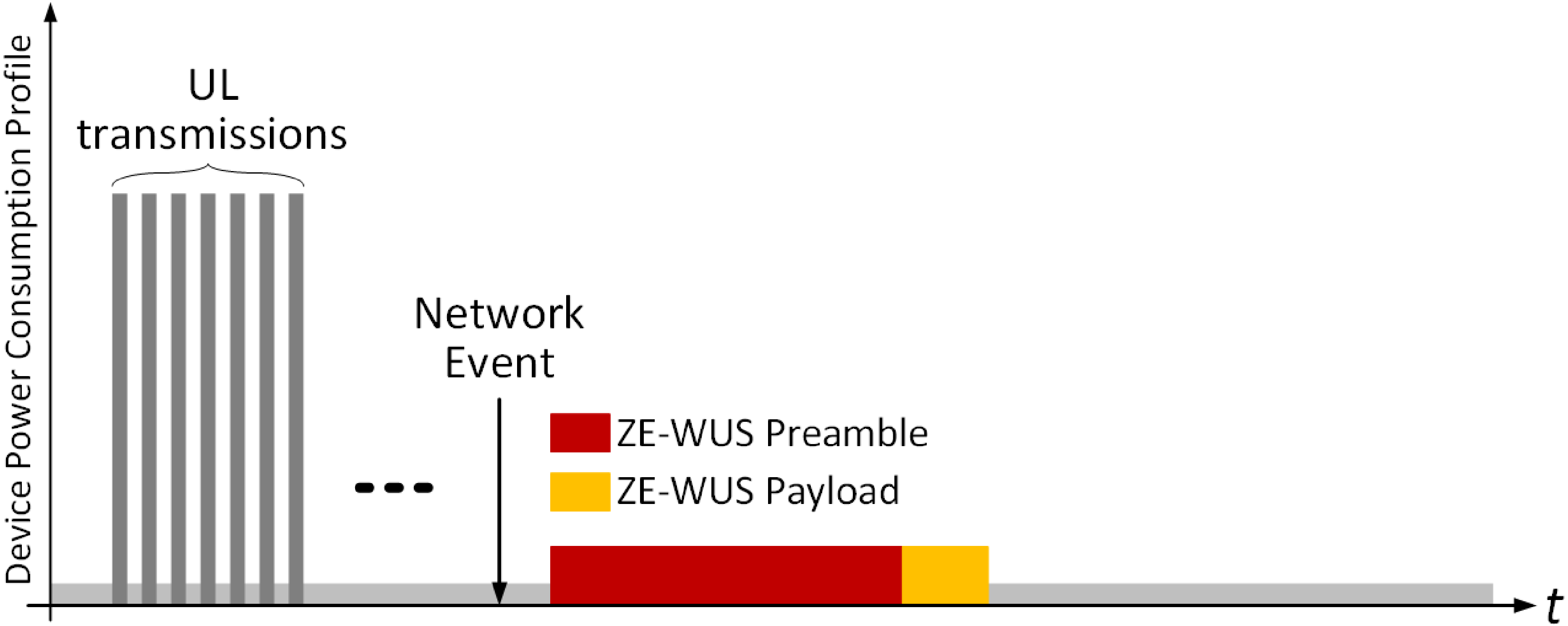
- ✓DRX/eDRX
- ✓PSM

Introducing On-Demand Features to 3GPP

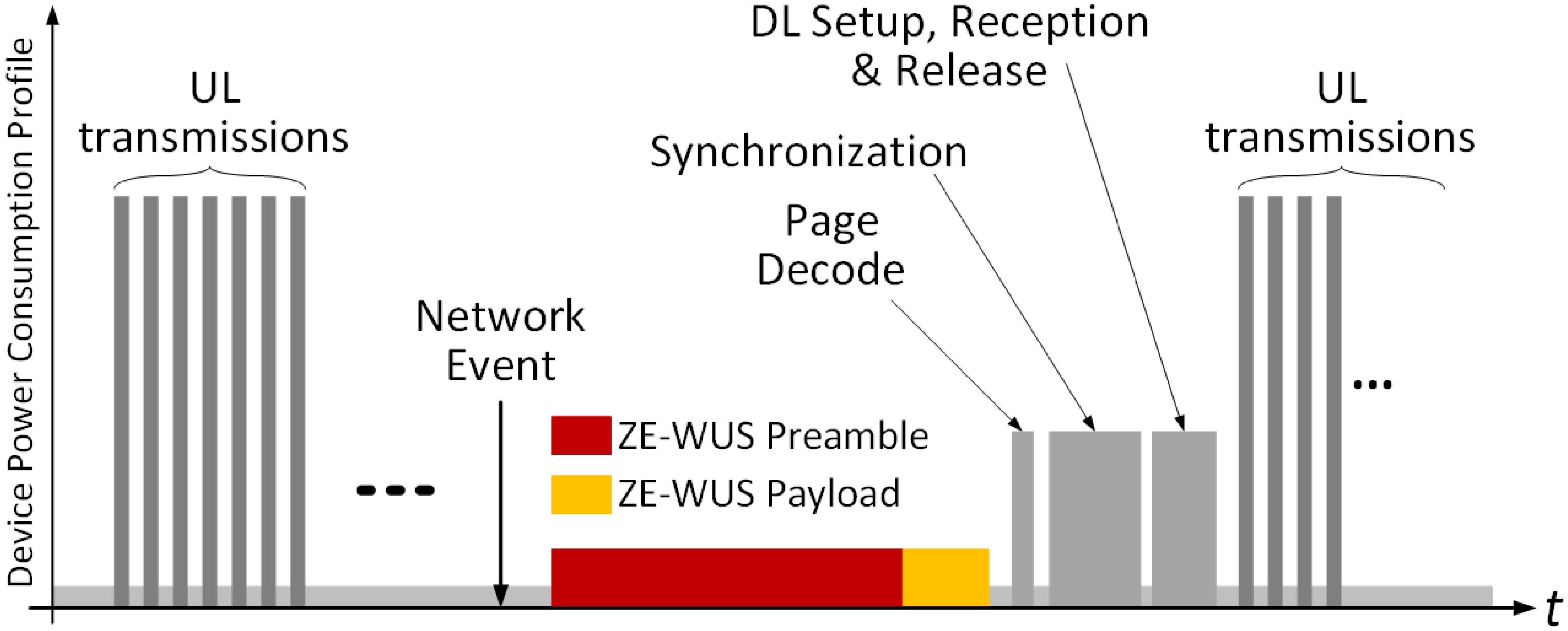
- Use the zero-energy (ZE) interface to introduce on-demand features to the 3GPP system framework
- Transmit on-demand wakeup signals that deliver power and information on the ZE interface
- Move mobility management related e.g. RSSI measurements to the ZE interface
- Dynamically control the device’s UL transmission repetition behavior using the ZE interface
- Transfer wireless power to devices using the ZE interface to compensate for the leakage power of the device in deep sleep mode

Introducing On-Demand Features to 3GPP

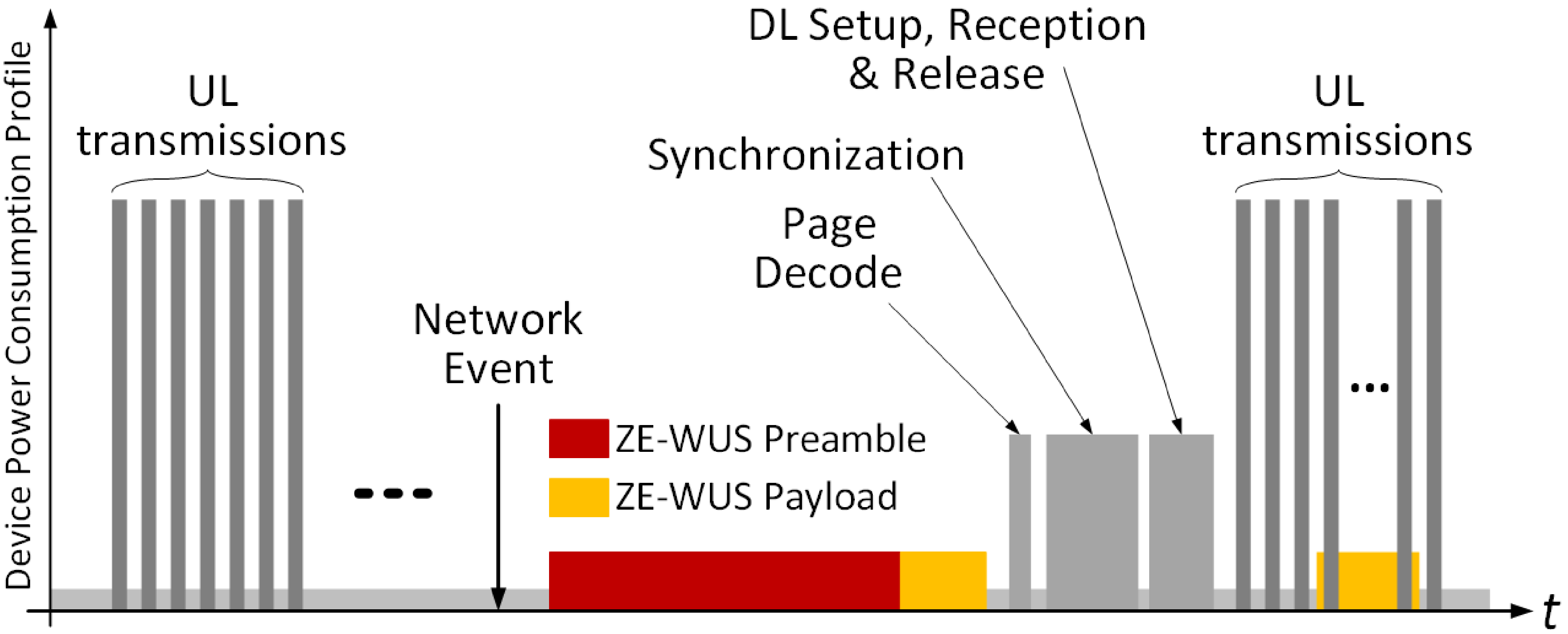
Introducing On-Demand Features to 3GPP



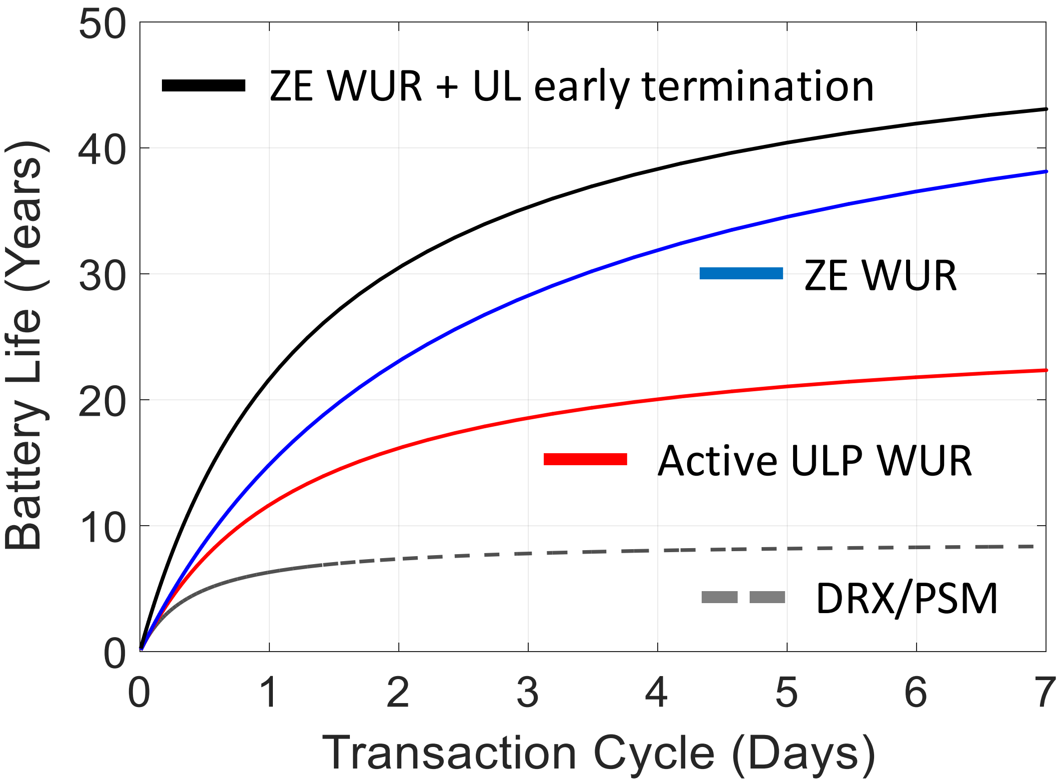
Introducing On-Demand Features to 3GPP



Introducing On-Demand Features to 3GPP



What is Achievable with a "Zero-Energy" Air-Interface?



- ❖ Two AA batteries
- ❖ UL packet size is 2-bytes
- ❖ Power class 4 transmitter

- ❖ 22 year battery life with a transaction cycle of 1 day
- ❖ 40 year battery life with a transaction cycle of 5 days

- ❖ Less than 1s network access latency

Concluding Remarks

- Scaling to 1T devices will require us to re-imagine the radio transceiver, the air-interface and the overall system
- Not all IoT verticals are created equal – we will need to break through the latency vs battery life tradeoffs in existing 3GPP duty-cycling approaches
- Ultra-low power receivers that consume few 10s of nanowatt power and are capable of macro-like link budgets will need to be developed
- On-demand features will have to be introduced to the 3GPP/NR system framework using a new class of "zero-energy" air-interfaces that concurrently deliver power and information to devices
- Using these PHY & MAC concepts a scalable system framework will have to be developed and integrated into future cellular networks!!

Thank you

Technology Evolution and Prototyping Team
InterDigital Communications

Hussain Elkotby, Marian Rudolf, Anantharaman Balasubramanian, Alpaslan Demir, Patrick Cabrol, Ravikumar Pragada

Tanbir Haque

tanbir.haque@interdigital.com